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Physicochemical Investigation of the Compatibilization of Polyolefin/Polyamide Blends: Morphology, Thermal Analysis and Specific Interactions*

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ABSTRACT

Morphological and physicochemical studies of the binary blends of a polyethylene-based ionomer with polypropylene, polyethylene and polyamide were undertaken to understand the influence of interfacial modification on the morphology and physical properties of compatibilized polyamide/ionomer/polyolefin ternary blends. A two phase morphology was observed for the binary polyolefin/ionomer blends, while in contrast the fracture surfaces of polyamide/ionomer blends appeared to be homogeneous. Infrared results indicated that a specific interaction exists between the carbonyl groups of the ionomer and the amide groups of the polyamide. This type of interaction was found to be absent between the ionomer and the polyolefins. At low ionomer concentrations, torque measurements displayed positive deviations for the polyamide/ionomer blends while negative deviations were observed for the polyolefin/ionomer blends. The results obtained from non-isothermal differential scanning calorimetry indicated that the ionomer enhanced the nucleation of the polyolefins, but impeded the crystallization of the polyamide. The spectrometric, calorimetric and physical data obtained for these binary blends concur with the morphological observations. This evidence suggests that there are much stronger interactions between the ionomer and the polyamide than between the ionomer and the polyolefins.

Running Title: Physicochemical Study of Polyolefin/Polyamide Blends

Keywords: Polymer blends, compatibilization, ionomer, crystallization, specific interactions and morphology.

INTRODUCTION

Polyamide/polyolefin blends compatiblized with an ionomer have potential applications as barrier materials, particularly with respect to hydrocarbon solvents [1-6]. The control of the morphology of the blend and the enhancement of interfacial interactions between the dispersed phase and the matrix are critical in order to improve the barrier properties of the blend. This article is one of a series of papers which considers the influence of interfacial modification on the morphology/processing relationships of compatibilized blends.

In previous work [7], the morpholgy of compatibilized polyamide/polyolefin blends, prepared by melt blending the resins in an internal mixing chamber, was studied quantitatively. The dimensions of the dispersed phase were significantly dependent upon the concentration of an ionomer compatibilizer in the blends. The phase size was found to have decreased by as much as three to four times with the addition of as little as 0.5% ionomer by weight to the blends. Moreover, the size reduction of the dispersed polyamide was greater than that of the dispersed polyolefins. These observations illustrate the interfacial activity of the ionomer in these compatiblized polyamide/polyolefin blends. However, a more detailed interpretation necessitates an understanding of the interactions which occur between the ionomer and the individual components of these blends.

In this paper, binary blends of the ionomer compatibilizer with each of the polyolefins and the polyamide were prepared in order to more favourably observe the interactions between the ionomer and these polymers. A Fourier transform infrared spectrometric study was performed on these binary blends, since vibrational spectroscopy has become an established technique for the characterization of specific interactions in polymer blends. Many studies have dealt with intermolecular hydrogen bonding and ionic interactions in ionomers and their blends [8-16]. The introduction of such specific interactions in blends is an important method of improving compatibility and may promote miscibility [17]. Thermal analysis is another important technique from which additional information can be obtained. In the literature, the fusion behaviour and crystallization kinetics of polymer blends have been studied in order to understand how one component of the blend affects the crystalline structure formed by the other component. An excellent review of these topics has been written recently by Martuscelli[18]. In addition, the results obtained from thermal analysis are important since impact resistance and many other properties are dependent on the crystalline structure of the blend components. In the past few years, more emphasis has been placed on non-isothermal crystallization. This type of study has been gaining importance since in reality, plastics processed in industry commonly experience non-isothermal treatments. It is primarily for this reason that the crystallization of the binary blends was studied under non-isothermal conditions in this paper.

Several studies of the morphology and properties of binary blends of polyamides with ethylene-based multifunctional copolymers can be found in the literature [19-24]. In all cases, a two phase morphology was observed for these blends. McKnight *et al.* [19] observed a reduction in the size of the dispersed ethylene-methacrylic acid copolymer phase as the acid content of the copolymer was increased. A detailed infrared spectrometric investigation of these blends showed that the enhanced compatibility at higher acid concentrations was attributed to amidation reactions occurring between the terminal amide groups of the polyamide and the carboxylic acid groups of the copolymer. Chuang and Han [20-22] have shown similar compatibility between polyamides and ethylene-based multifunctional copolymers, where the size of the dispersed copolymer diminished as the reactivity of the copolymer increased. Blends of polyamide with maleic anhydride grafted ethylene-propylene random copolymers were found by Cimmino *et al.* [23,24] to display a much finer morphology than that observed for the blends containing unmodified elastomers.

In the above studies, the effect of introducing specific interactions, or actually inducing reactions between the polymers at the interface has not only produced a finer dispersion but also gives rise to blends having superior properties. The impact resistance [22-24] and tensile properties [20,22,23] of these blends showed marked improvements in comparison to blends where no interactions were present. For blends of polyamide with ethylene-based multifunctional copolymers, the measured values of the viscosity were higher than the values

predicted by Taylor's equation [20-22]. In one of the few studies dealing with the properties of blends of polyolefins with ethylene-methacrylic acid copolymers, Fairley and Prud'Homme [23] also observed an improvement in the tensile properties of these blends. However, the melting and crystallization of one component of the blend was not affected by the second comnponent, as observed from the results obtained from light scattering and differential scanning calorimetry. These authors interpreted this effect as an absence of specific interactions occurring between the blend components.

The objective of this paper is to arrive at an understanding of the role of the polyethylene-based ionomer as an interfacial modifier in polyolefin/polyamide blends. The results of the morphological and physicochemical studies of binary blends of the ionomer with polypropylene, polyethylene and polyamide are presented.

EXPERIMENTAL

Resin Characterization

The polypropylene (PP) resin, Pro-fax 6501, was received from Himont in powdered form. This resin was compounded with an antioxidant, Irganox 1076 (Ciba-Geigy), on a twin screw extruder and transformed into pellets. The high density polyethylene (PE) resin, 07055C, was obtained from Dow as

pellets. The polyamide-6 (PA) resin, Zytel 211, was obtained from Dupont, also in the form of pellets. None of these resins contain nucleating agents.

The ionomer used in this study, Surlyn 9020 from Dupont, is a random terpolymer consisting of roughly 80% polyethylene and 20% of a mixture of methacrylic acid and isobutyl acrylate. The exact proportion of this mixture is unknown. The methacrylic acid is partially neutralized with zinc to approximately 70%.

Some properties obtained for these resins are given in Table 1. It was possible to determine the torque of each resin by mixing 60 ml of the resin in the Brabender mixing chamber at 250°C for 5 min with the rotors turning at 50 RPM. The torque (N.m) represents a measure of the work required to turn the rotors in the mixing chamber. The densities of the resins were determined after they had been mixed in the Brabender, and are also reported in Table 1.

The storage modulus and dynamic viscosity of each resin were obtained as a function of frequency at 250°C, using a Rheometrics Mechanical Spectrometer (model RMS 605). The values of the storage modulus and dynamic viscosity at 100 rad s^{-1} are given in Table 1, and the frequency sweeps presented elsewhere [7]. The instrument was operated in the dynamic mode, with a gap of 1.2 $\pm$ 0.1 mm between parallel plates. All experiments were performed under dry nitrogen.

Compounding

The resins were dry blended and dried under vacuum at 95°C overnight. It may be mentioned that throughout the text, the blend compositions are given in terms of weight fraction. The mixed pellets were then melt blended in the Brabender mixing chamber using the roller blades recommended for high shear applications. A typical blending experiment consisted of the following steps. With the mixing chamber initially set at 250°C and the blades turning at 50 RPM, the resin mixture was fed into the chamber. Once all of the resin was added, the blend was allowed to mix for 5 min under a constant flow of dry nitrogen. At the end of 5 min, the melt was rapidly transferred to a mould which was then held in a hydraulic press under 2.5 MPa of pressure until the sample had cooled down to room temperature (approximately 3 min). The morphology of a blend prepared in this manner was found to be identical to that observed for a blend which was simply removed from the mixing chamber and rapidly quenched in ice water.

Scanning Electron Microscopy

The freeze fractured surfaces were prepared by first immersing a small rectangular strip of each sample in liquid nitrogen for 10-15 min prior to fracturing. The surfaces of each

blend were then examined under the scanning electron microscope (SEM, Jeol model 35-CF), operating at 10-15 kV.

Image Analysis

The semi-automatic image analyzer used to measure the diameters of the dispersed phase was developed in-house. The operation of this instrument has been described elsewhere [26]. For each sample, approximately 200 diameter measurements were obtained from the SEM photomicrographs.

Fourier Transform Infrared Spectrometry

In preparation for the infrared measurements, rectangular specimens were cut from the moulded blend samples to have dimensions of roughly 1 x 1.5 x 0.5 cm. A Reichert Jung Supercut 2050 microtome equipped with a diamond knife was used to cut films 2 to 5 μm thick from these specimens. The infrared spectra were then measured in transmission using a Nicolet Fourier Transform infrared spectrometer (FTIR). For each sample, 128 scans were accumulated before the Fourier transformation.

Differential Scanning Calorimetry

A Setaram differential scanning calorimeter (DSC) was used to observe the crystallization of the pure resins and their binary blends. The samples were held in the melt for 6 min before

recording the crystallization at a cooling rate of 5°C min^{-1}. The quantity of material analyzed was 100 ± 20 mg. All experiments were performed under a constant flow of dry nitrogen.

RESULTS AND DISCUSSION

Morphology of Polyolefin/Ionomer Binary Blends

The SEM photomicrographs obtained for binary blends of polypropylene with 20%, 50% and 80% ionomer are shown in Figure 1. The two phases are distinct for each composition. There is no evidence of adhesion between the dispersed phase and the matrix. The same observations were made for the binary blends of polyethylene with the ionomer, also shown in Figure 1.

The number average diameters of the dispersed phase were determined for these blends, and the results shown in Figure 2. As the weight percent of the dispersed phase increases, larger domain sizes are observed for the dispersed polymer. This type of phase size/composition relationship is generally observed for immiscible blends [26-31]. In addition, the size of ionomer domains dispersed in a polyethylene matrix is slightly larger than that observed for ionomer dispersed in polypropylene. From the resin properties given in Table 1, it can be seen that torque ratios (ratio of the torque of the dispersed phase to that of the matrix) and viscosity ratios are quite close for these two blends. It is also likely that the interfacial tensions are very

similar [32]. The elasticity ratio is the principal parameter which varies, where the ratio of the PE/ionomer blend is more than twice that of the PP/ionomer blend. Although some reference has been made to the dependence of phase size and shape on elasticity [33-35], its overall influence on blend morphology is not well understood.

When the blends are inverted, such that the polyolefins are dispersed in the ionomer, the torque ratios become very small and have values of about 0.5. This viscosity effect is reflected in the reduction in the size of the dispersed polyolefins relative to that of dispersed ionomer, and can be seen in Figure 2 at high ionomer concentrations. The dependence of phase size on torque ratio (viscosity ratio) has been investigated recently by Favis and Chalifoux [36] for polypropylene/polycarbonate blends.

Morphology of Polyamide/Ionomer Binary Blends

The morphology of the binary polyamide/ionomer blends was found to be very different from the corresponding polyolefin blends. Figure 1 illustrates the SEM photomicrographs obtained for the polyamide blends containing 20%, 50% and 80% ionomer. For each composition, these binary blends appear homogeneous: it is not possible to observe the presence of a dispersed phase. This absence of minor phase was also observed by Van Gheluwe *et al.* [37] in a study of the mechanical properties of extruded PA/ionomer/PP blends. However, when the microtomed surface of the 80%PA/20%ionomer binary blend is etched to remove the dispersed

ionomer domains located at the surface [7], the dispersed phase is readily observed as shown in Figure 3. The size of the dispersed ionomer domains is extremely small. The number average diameter determined for the 80%PA/20%ionomer blend is only 0.15 μm, roughly 5 times smaller than the corresponding polypropylene blend. Therefore, from a morphological standpoint, it appears that the polyamide/ionomer blend is significantly more compatible than the polyolefin/ionomer blends.

Torque Measurements

The torques measured for the polypropylene/ionomer blends during melt mixing in the Brabender are shown in Figure 4a. A negative deviation can be seen between the measured points and the tie-line joining the torques of the pure components, over the whole composition range. At low ionomer contents, the torque of the blend is actually lower than that of the polypropylene resin. This shape of torque/composition curve is characteristic of an incompatible blend [33]. In such cases, there is a significant degree of interlayer slip occurring at the interface during the melt blending [33].

For the polyethylene/ionomer blends, a curve approaching additive behaviour was observed, as shown in Figure 4b. This is particularly true at low ionomer concentrations. Thus, it is possible that there are stronger interfacial interactions occurring between the polyethylene and the ionomer in comparison to those between the polypropylene and the ionomer.

For the binary blends of polyamide with the ionomer, a strong positive deviation was found for the torque at low ionomer contents, as shown in Figure 4c. This is quite different from what was observed for the polyolefins at low ionomer concentrations. The positive deviation suggests that there are strong interactions between the polyamide and the ionomer. At high ionomer contents, the torque displays a slight negative deviation from additivity.

Specific Interactions

The FTIR absorbance spectra measured for the pure ionomer and the blends containing 50% ionomer are shown in Figure 5. In the spectrum corresponding to the ionomer, the hydrogen bonded carbonyl stretching frequency can be seen at 1699 cm^{-1}, while that of the non-hydrogen bonded carbonyls appears at 1735 cm^{-1}. For the 50%PA/50%ionomer blend, the three peaks appearing in the carbonyl frequency region are well resolved: the two bands at the higher frequencies correspond to the ionomer, while the absorbance band appearing at 1620 cm^{-1} corresponds to both hydrogen bonded and non-hydrogen bonded carbonyl stretching frequencies of the polyamide.

It should be possible to monitor changes in the hydrogen bonding of the ionomer carbonyl groups as a result of interactions which may have occured during the melt mixing with the polyolefins and the polyamide. Several types of hydrogen bonding are possible. For example, ionomer carbonyl groups can

interact with OH groups on adjacent ionomer chains. In fact, the tightly packed structure of ionomers, often referred to as ion clusters, is the result of strong intermolecular associations such as cyclic double hydrogen bonds or carboxylic acid dimers[14]. However, as shown by Read and Stein [39] and Ogura and Sobue [40], neutralization of the carboxylic acid disrupts the formation of such cyclic bonds. Since the methacrylic acid in the ionomer used in our study is neutralized by zinc ions to approximately 70%, there is only a slight possibility that such cyclic hydrogen bonds would occur. It is also possible for the CO groups of the polyamide to undergo hydrogen bonding with the OH groups of the ionomer. However, the width at half height, $W_{1/2}$, of the polyamide carbonyl band at 1620 cm^{-1} did not change with ionomer content. Since $W_{1/2}$ normally increases with hydrogen bonding [41], this suggests that this carbonyl band was not experiencing any changes in hydrogen bonding. After a study of the various possibilities above, the most likely interaction was considered to be hydrogen bonding between the ionomer CO groups and the polyamide NH groups.

By determining the ratio of the area of the absorbance peak at 1699 cm^{-1} to that at 1735 cm^{-1} (A_{1699}/A_{1735}), it is possible to follow the changes in the hydrogen bonding of the ionomer CO groups. The dependence of the ratio of the areas of the ionomer carbonyl absorbance bands on the composition of the binary blends is shown in Figure 6. When the ionomer forms the matrix in these blends, that is between 70% and 100% ionomer, there is essentially no change in the A_{1699}/A_{1735} ratio. At ionomer

concentrations lower than 60%, no change is observed for the A_{1690}/A_{1735} ratio corresponding to the polyolefin binary blends. In contrast, for the polyamide blend, the A_{1690}/A_{1735} ratio increases at lower ionomer concentrations. This indicates that the hydrogen bonding of the ionomer in these blends is enhanced over that in the pure ionomer. It may be mentioned that it is not possible to differentiate between the contribution of the methacrylic acid or isobutylacrylate to the hydrogen bonding.

Since it is most probable that the enhanced hydrogen bonding observed for the carbonyl groups of the ionomer in Figure 6 is the result of a specific interaction with the amine groups of the polyamide, then this interaction should also manifest itself in the amine bands of the polyamide in the FTIR spectrum of the blend. From the spectrum measured for the 50%PA/50%ionomer blend shown in Figure 5, these bands can be seen between 3000 and 3600 cm^{-1}. For the pure polyamide resin, the NH band at 3300 cm^{-1} is the most intense, and represents single hydrogen bonded amines occurring between NH and CO functionalities present on adjacent polyamide chains. The shoulder at 3200 cm^{-1} represents the cyclic intramolecular C=O---H-N bond, while the small peak at 3080 cm^{-1} corresponds to cyclic double hydrogen bonds occurring between adjacent polyamide chains. Non-hydrogen bonded amines give rise to a very weak band at 3500 cm^{-1} [41-43].

Any interaction occurring between the polyamide and the ionomer would disrupt the interchain hydrogen bonding of the polyamide and result in a decrease in the intensity of the 3080 cm^{-1} band. There would also be a concomitant increase in the

intensity of the band at 3300 cm^{-1} as new single N-H---O=C hydrogen bonds are formed. In this case, it is assumed that the new N-H---O=C(ionomer) hydrogen bonds appear at the same wavenumber as the N-H---O=C(PA) hydrogen bonds occurring in the polyamide resin. Thus, as the extent of hydrogen bonding between the polyamide and the ionomer increases, the ratio of the area of the absorption peak at 3300 cm^{-1} to that at 3080 cm^{-1} (A_{3300}/A_{3080}) should increase. As shown in Figure 7, this ratio does in fact increase with ionomer content until 30%, after which the A_{3300}/A_{3080} ratio decreases. The increase in the ratio observed for the PA/ionomer binary blend is much greater than that measured for an incompatible polyamide/high density polyethylene (HDPE) binary blend, also shown in Figure 7. The increase in the ratio observed for this blend is probably due to a dilution effect between the polyamide and the polyethylene. Therefore, the results presented in Figures 6 and 7 confirm that there is a hydrogen bonding interaction between the polyamide and the ionomer, which is absent between the polyolefins and the ionomer.

In a study of the binary blends of polyamide and ethylene-methacrylic acid copolymers, McKnight *et al.* [9] suggested that graft copolymers were formed at the interface between the two phases as a result of amidation reactions taking place during melt mixing. It is interesting that no evidence of such reactions was observed for the polyamide/ionomer binary blends studied in this paper. This is probably due to the fact that more than 70% of the methacrylic acid groups of the ionomer

are neutralized by zinc. The salt form of the acid would thus inhibit the amidation reaction.

Thermal Analysis

The crystallization exotherms of the binary blends of polypropylene, polyethylene and polyamide with 30% ionomer are shown in Figure 8. Each crystallization trace is characterized by two peaks: one rather broad peak corresponding to the ionomer, and a sharper peak corresponding to the other component. Only the peaks corresponding to the polyolefins and the polyamide were analyzed since the ionomer peaks were too broad to allow for an accurate analysis.

The areas of the crystallization exotherms were integrated as a function of temperature (equivalent to time since the DSC scans were performed at 5°C min^{-1}). Thus, the percent transformation of crystalline material is the ratio of the area measured up to temperature T divided by the total area. It is possible to determine the halftime, $t_{1/2}$, of the crystallization process by measuring the difference between the temperature corresponding to 50% transformation and the temperature corresponding to the onset of crystallization, divided by the scan rate. Figure 9 illustrates the dependence of the crystallization halftimes of the polyolefins and polyamide on the ionomer content of the corresponding binary blends. For the PP/ionomer blends, there is an initial sharp decrease followed by an equilibration of the halftime. The reduction observed for the

halftime indicates that the ionomer is accelerating the crystallization of the polypropylene, and is possibly acting as a nucleating agent. For the PE/ionomer blends, there is only a slight decrease in the halftime. However, in contrast to what was observed for the polyolefins, the halftime of the PA/ionomer blends increases dramatically. This indicates that the crystallization process is impeded by the presence of the ionomer in these blends. This result was expected in view of the strong interactions which have been found to occur between the polyamide and the ionomer, using FTIR spectrometry.

The temperature corresponding to the maximum of the crystallization exotherms, T_c, are shown in Figure 10 for the binary blends, as a function of ionomer concentration. A significant increase in T_c was observed for the PP/ionomer blends which again suggests that the ionomer is behaving as a nucleating agent for polypropylene. The smaller increase observed for the PE/ionomer blends indicates that there is also a slight nucleating effect for polyethylene. In contrast, the maximum crystallization temperature of the PA/ionomer blends decreased with ionomer concentration. This concurs with the increase in the halftime of the crystallization, and indicates that the ionomer is interfering with the crystallization of the polyamide in these blends.

Recently, Caldas *et al.* [44] studied the isothermal spherulitic growth of polypropylene in PP/ionomer blends. The nucleating ability of the ionomer for polypropylene was demonstrated directly using optical microscopy. However, it was

not possible to verify the nucleation of the PE/ionomer and PA/ionomer blends since the polyethylene and polyamide polymers themselves are inherently highly self-nucleating. In Figures 9 and 10, it can be seen that the crystallization behaviour of the PP/ionomer and the PE/ionomer blends are very similar in the range of 10% to 60% ionomer. However, at concentrations lower than 10% ionomer, significant differences were observed, with very high $t_{1/2}$ and very low T_c values observed for polypropylene relative to polyethylene. A possible explanation may be that at concentrations lower than 10% ionomer, nucleation effects are more closely related to the nucleation density of the polyolefin itself. Polyethylene is more highly self-nucleating than polypropylene. At higher concentrations, the ionomer begins to effectively nucleate the polypropylene as well.

The width of the crystallization exotherms measured at half height, $W_{1/2}$, are given in Figure 11 for the three binary blends. For the PP/ionomer blend, the $W_{1/2}$ value does not change with ionomer concentration, indicating that the distribution of crystallite size is unaffected by the presence of ionomer. In a study of PP/PE blends, Gupta *et al.* [43] noticed that although the nucleation of the polypropylene was enhanced by the dispersion of polyethylene in the polypropylene matrix, a narrower crystallite size distribution was observed.

An increase in the width at half height was observed for the PE/ionomer blends as a function of ionomer concentration. It is evident that the presence of ionomer in the polyethylene/ionomer blend has severely influenced the growth of

the polyethylene crystallites. However, it is not likely that co-crystallization is occurring in the PE/ionomer blend as a result of the work performed by Kyu and Vadhar as well as others [46-51]. These authors have shown that co-crystallization only occurs between different linear polyethylenes but not between linear and branched polyethylenes, the latter being representative of the PE/ionomer blend used in this study. Thus, the influence of the ionomer on the crystal growth of the polyethylene may be the result of the natural affinity between the polyethylene matrix and the polyethylene moiety of the ionomer.

For the polyamide/ionomer blends, a more pronounced increase in the width at half height with ionomer concentration was observed in comparison to the PE/ionomer blend. This result would be expected if the ionomer is interfering with the crystallization of the polyamide. Thus, a much wider distribution of polyamide crystallites occurs as a result of blending with the ionomer.

The relative crystallinity measured for the three binary blends is shown in Figure 12. This value is determined by taking the ratio of the area of the crystallization exotherm of the blend to that of the pure polymer. It can be seen that the relative crystallinity follows the same trends as the crystallite size data presented in Figure 11. From these results, an apparent heirarchy can be postulated for the interactions which occur between the polymers and the ionomer: strong for polyamide, intermediate for polyethylene, and essentially nil for polypropylene. Although definite trends are observed, the results

given in Figure 12 differ by only ± 5% which suggests that the measurement of crystallinity is not highly sensitive to the interactions occurring between these polymers. Such observations were also made by Chuang and Han [20,21], McKnight et al. [19] and Fairley and Prud'homme [25] for similar types of systems.

CONCLUDING REMARKS

From the SEM photomicrographs, it can be seen that the PA/ionomer blend is morphologically very different from the polyolefin/ionomer blends. The PA/ionomer blend appears homogeneous - this visual absence of minor phase suggests the presence of specific interactions between the polyamide and the ionomer. The two phase morphology observed for the polyolefin/ionomer blends is that typical of immiscible blends. Moreover, the torque measurements display positive deviations for the PA/ionomer blends at low ionomer concentrations, while the polyolefin/ionomer blends display the negative deviations also typical of immiscible blends. The positive deviations observed for the PA/ionomer blends allude to stronger interactions occurring between the polyamide and the ionomer than between the polyolefins and the ionomer. Analysis of the infrared spectra of these binary blends allowed the specific interactions to be identified as hydrogen bonding between the amine groups of the polyamide and the carbonyl groups of the ionomer. This type of interaction is not present in the polyolefin/ionomer blends.

From the thermal analysis studies, the ionomer was found to behave as a nucleating agent for polypropylene, without altering its crystal structure. Polyethylene is also nucleated by the ionomer, but the chemical similarity between polyethylene and the ionomer gives rise to significant changes in the crystallite size of the polyethylene. The crystallization of the polyamide is impeded by the presence of ionomer, and the distribution of lamellar thicknesses is even wider than that observed for the polyethylene.

In previous work [7], when the ionomer was added to polyolefin/polyamide blends as an interfacial agent or compatibilizer, the size of the dispersed polyamide phase was reduced to a more significant extent than that of dispersed polyethylene or polypropylene. It was speculated that the ionomer had a greater affinity for the polyamide than either of the polyolefins. In the present study, the interactions were maximized by preparing binary blends of the ionomer with the polyamide and the polyolefins. The morphology, flow properties, specific interactions as measured by FTIR, and crystallization phenomena all confirm the greater affinity of the ionomer for the polyamide.

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FIGURE CAPTIONS

1- SEM photomicrographs of fracture surfaces of PP/ionomer, PE/ionomer and PA/ionomer binary blends, containing 20%, 50% and 80% ionomer. All photomicrographs were taken at the same magnification.

2- The number average diameters determined for the binary PP/ionomer and PE/ionomer blends, as a function of ionomer concentration.

3- SEM photomicrograph of the microtomed/etched surface observed for the 80%PA/20%ionomer binary blend.

4- The torques measured in the Brabender at 250°C for the a) PP/ionomer, b) PE/ionomer and c) PA/ionomer binary blends, as a function of ionomer concentration.

5- FTIR spectra of the 50%PP/50%ionomer, 50%PE/50%ionomer, and 50%PA/50%ionomer binary blends, as well as the ionomer resin, measured in transmission.

6- The ratio of the area of the ionomer carbonyl band at 1699 cm^{-1} to that at 1735 cm^{-1}, A_{1699}/A_{1735}, determined from the FTIR spectra of the PP/ionomer, PE/ionomer and PA/ionomer binary blends.

7- The ratio of the area of the polyamide amine band at 3300 cm^{-1} to that at 3080 cm^{-1}, A_{3300}/A_{3080}, determined from the FTIR spectra of the PA/ionomer and PA/HDPE binary blends.

8- The crystallization exotherms observed for the binary blends of a) polypropylene, b) polyethylene and c) polyamide with 30% ionomer, obtained at 5°C min^{-1}.

9- The crystallization halftimes, $t_{1/2}$, measured for the binary blends as a function of ionomer concentration.

10- The maximum crystallization temperatures, T_c, observed for the a) PP/ionomer and PE/ionomer, and b) PA/ionomer binary blends, as a function of ionomer concentration.

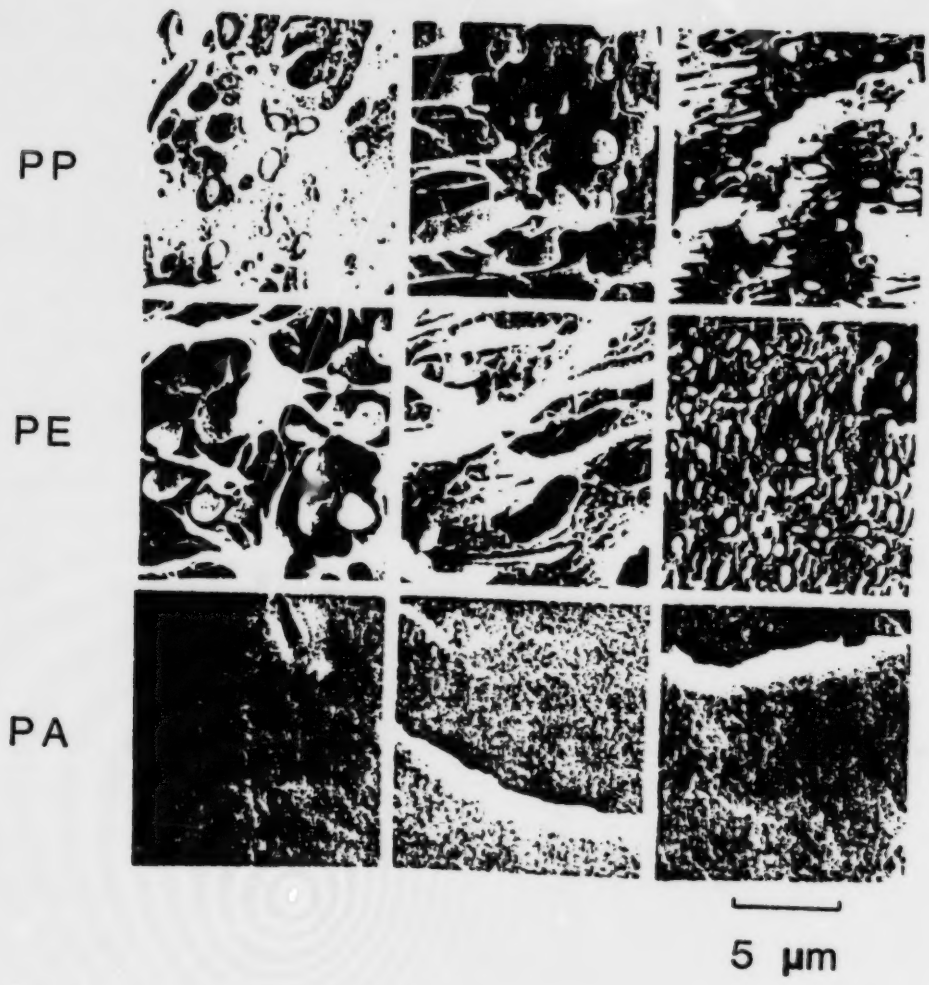
11- The widths at half height of the crystallization exotherms, measured for the binary blends as a function of ionomer concentration.

12- The relative crystallinity of polypropylene, polyethylene and polyamide in the binary blends, as a function of ionomer concentration.

'ABLE 1: Characterization of the Surlyn ionomer, polypropylene, polyethylene nd polyamide-6 resins.

ESIN	MELT INDEX (g/10min)	DENSITY (g ml^{-1}) @ 250°C	TORQUE (N m) @ 250°C	DYNAMIC* VISCOSITY x 10^{-3} (Pa s)	STORAGE* MODULUS x 10^{-4} (Pa)
urlyn	1.0	0.74	14.3	5.0	4.6
P	4.0	0.75	8.6	3.2	3.6
E	7.0	0.74	5.9	3.0	1.5
A	-	0.96	8.6	6.2	2.6

- @ 250°C and 100 rad s^{-1}.



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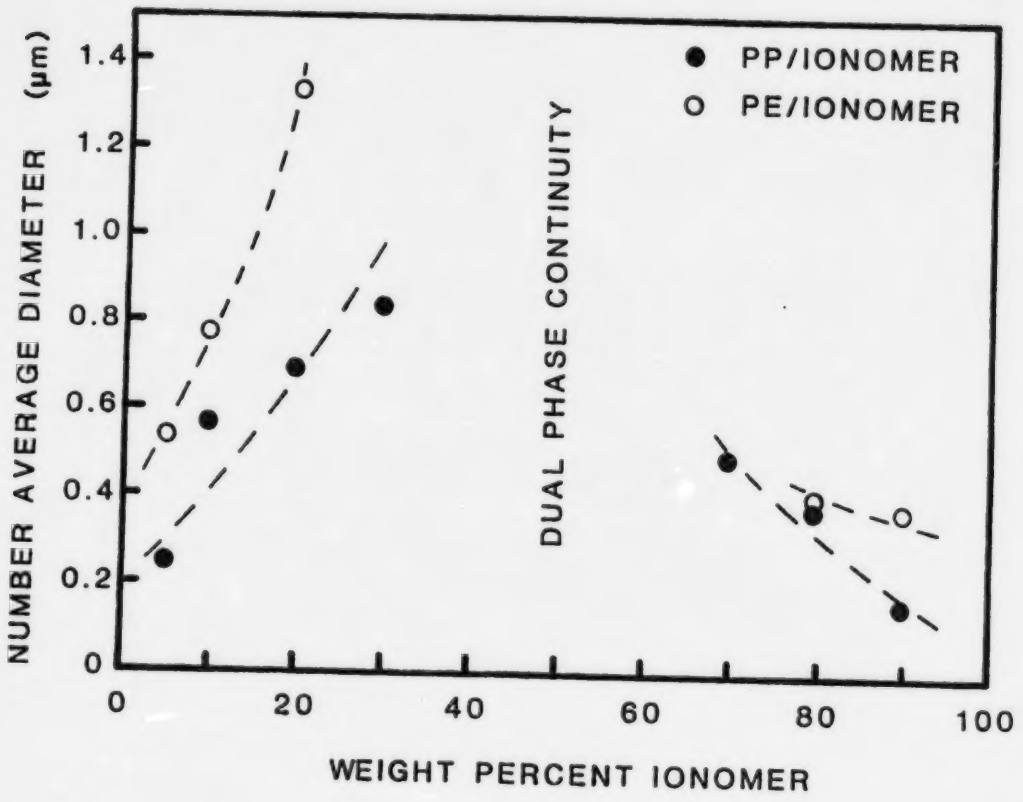
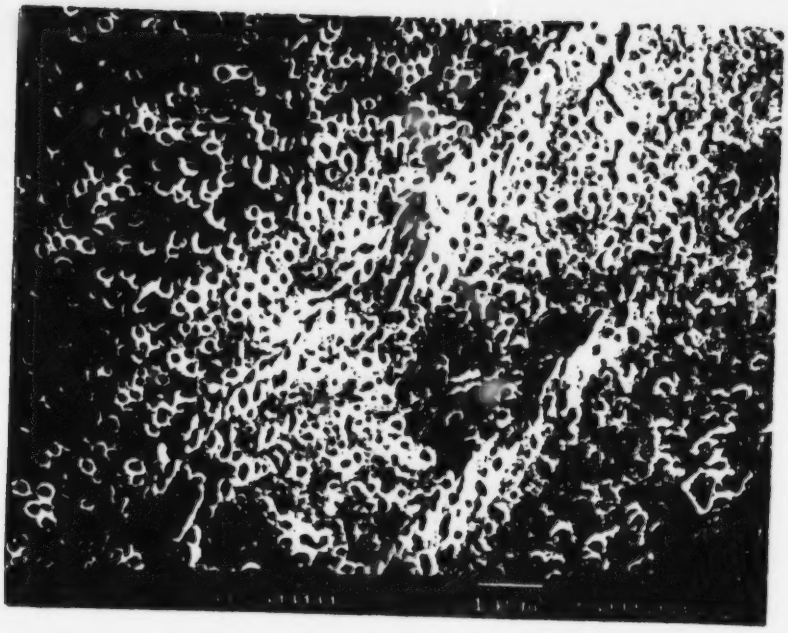


2- The number average diameters determined for the binary PP/ionomer and PE/ionomer blends, as a function of ionomer concentration.



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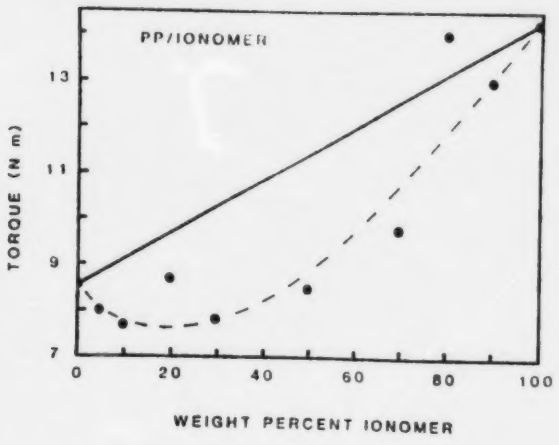
a)



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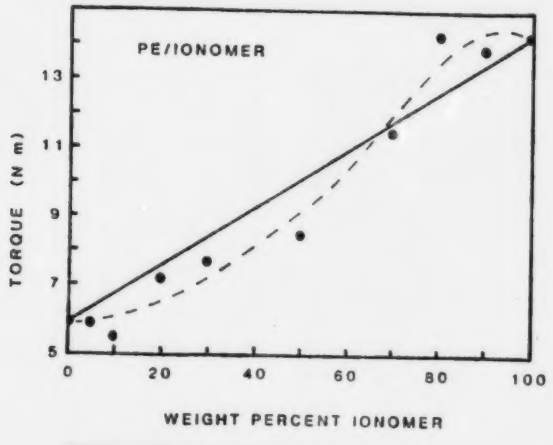
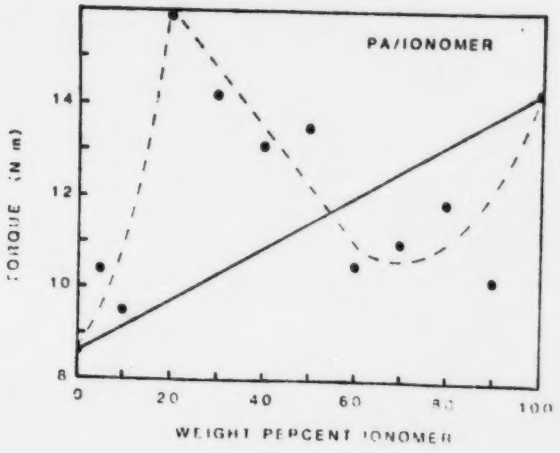


c)



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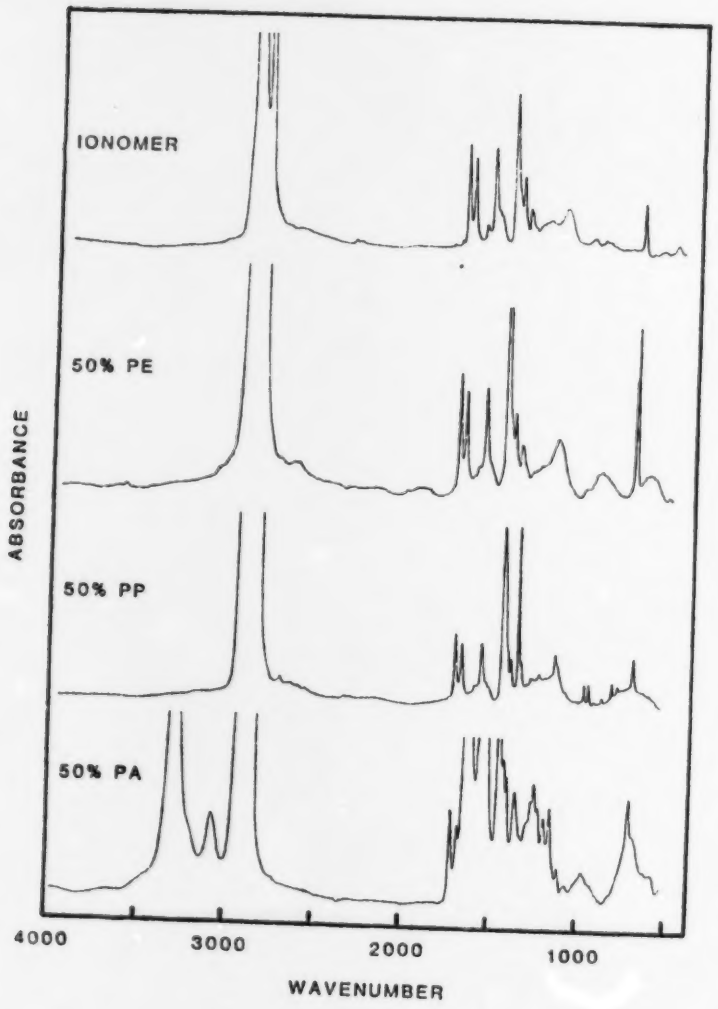

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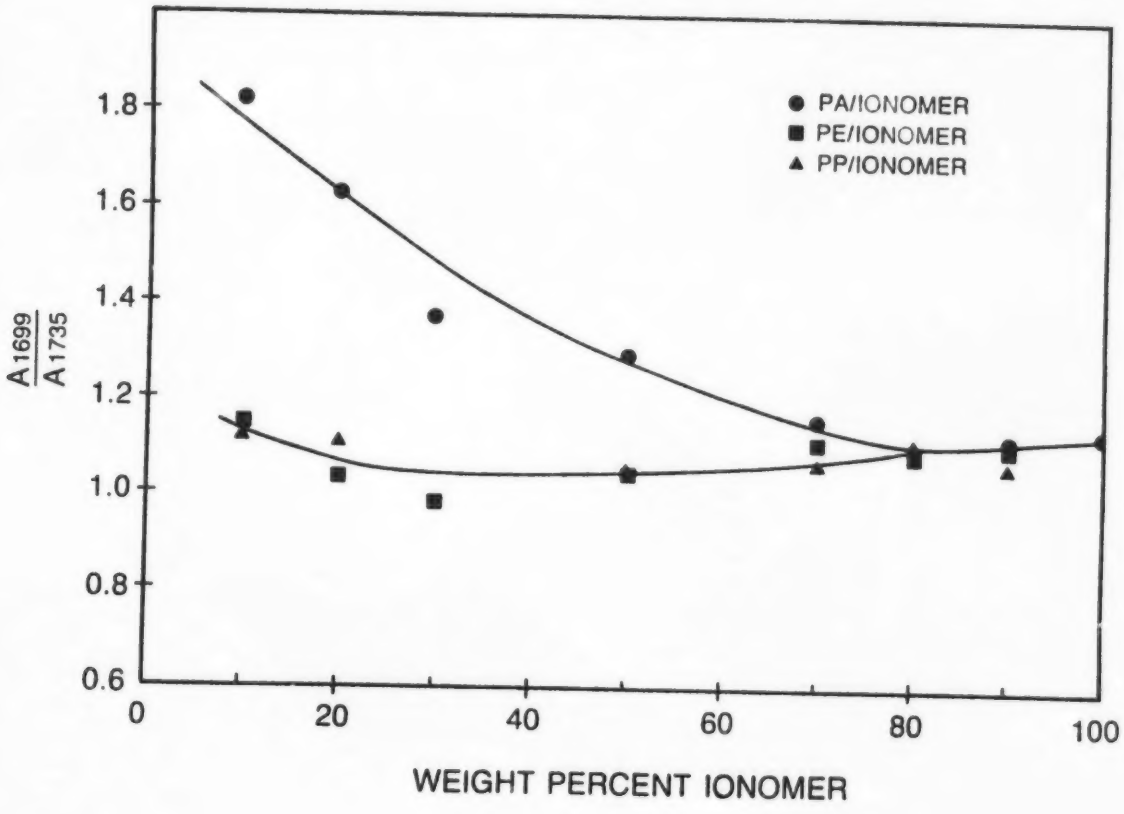

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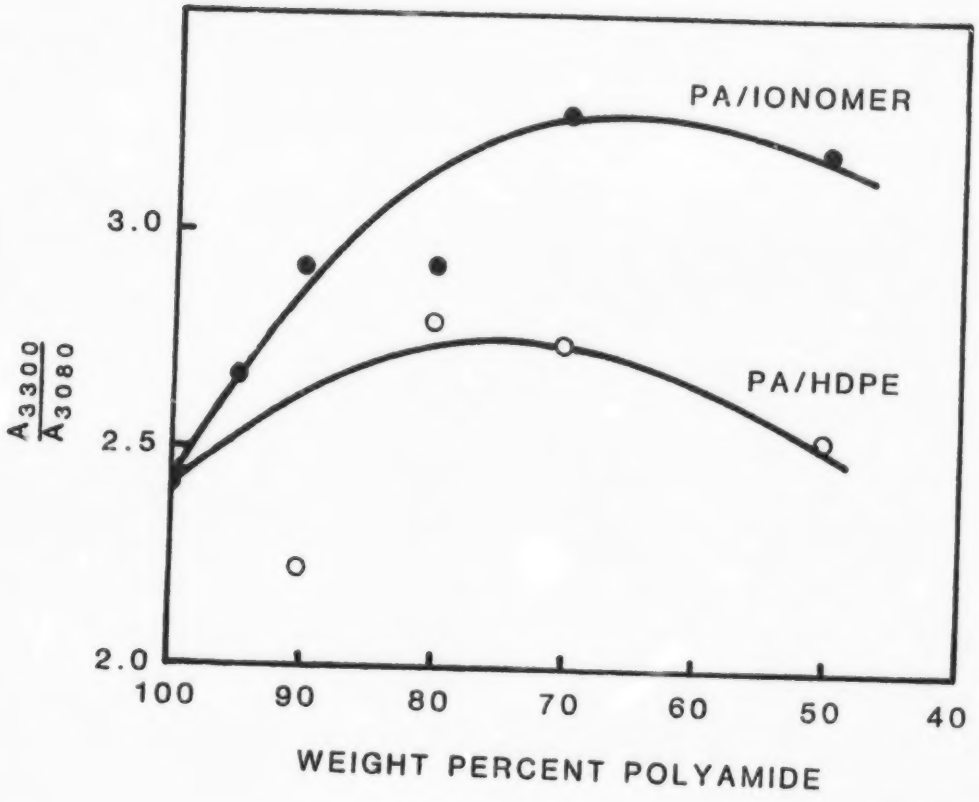

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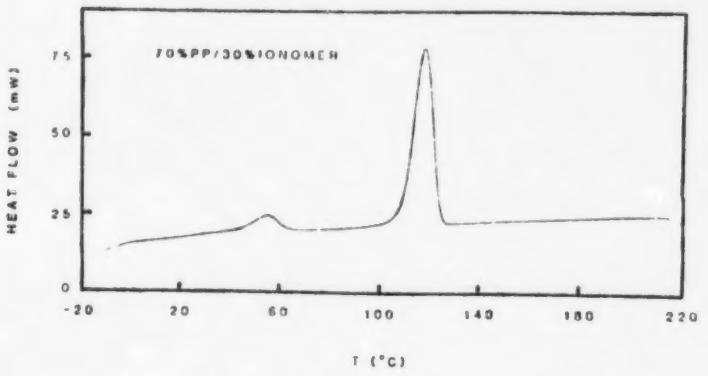

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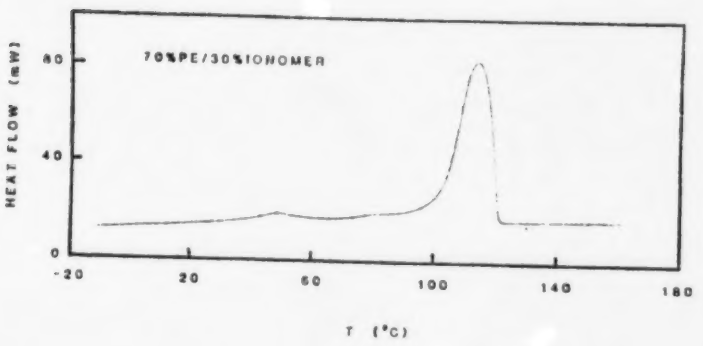
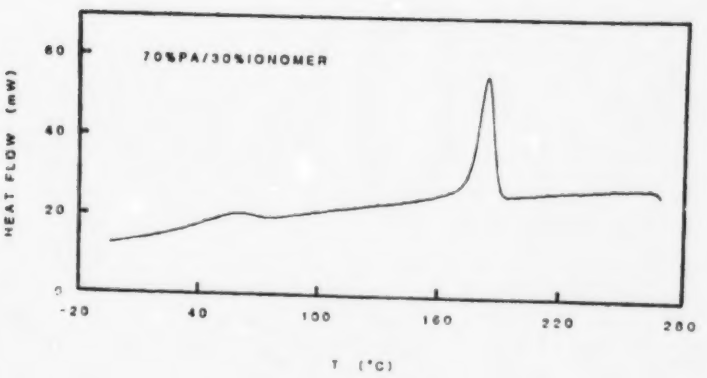
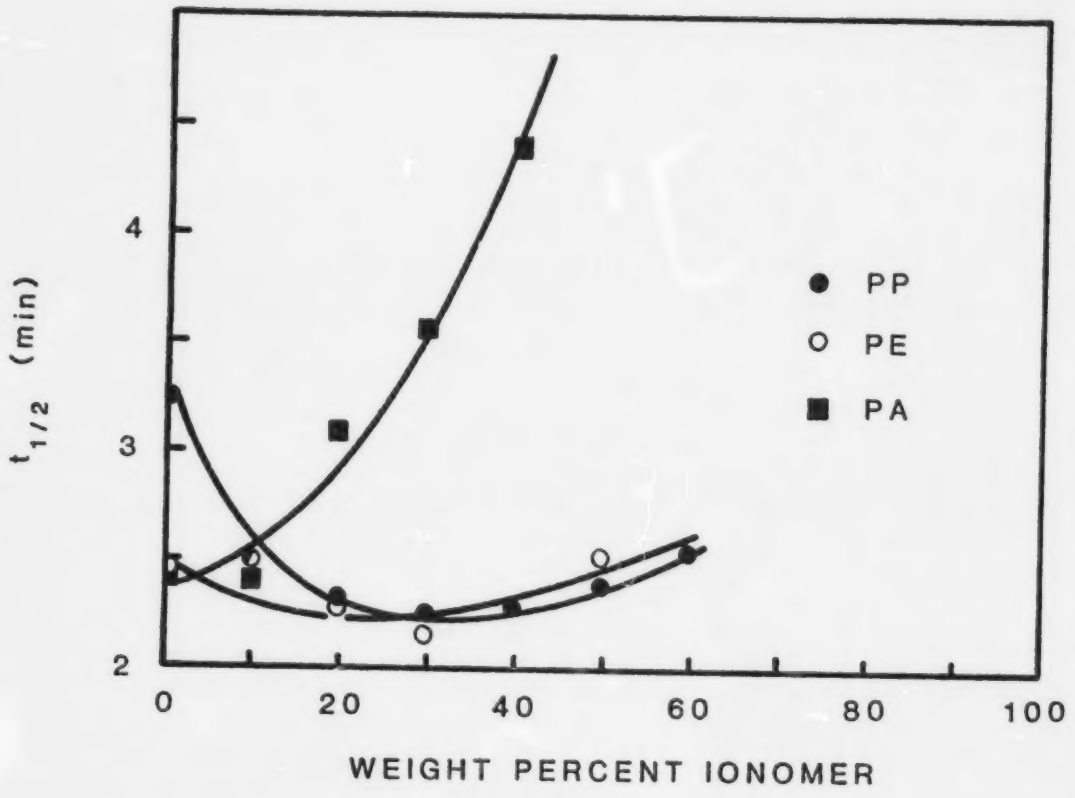


c)



f- The crystallization exotherms observed for the binary blends of a) polypropylene, b) polyethylene and c) polyamide with 30% ionomer, obtained at 5°C min^{-1}.



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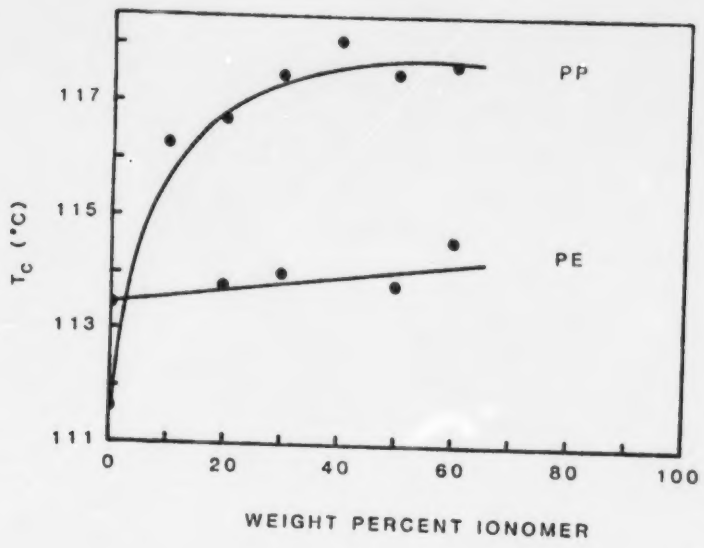
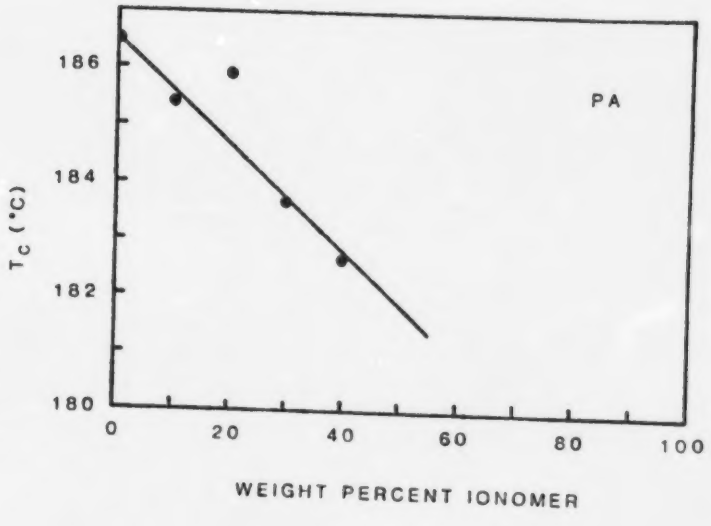


b)



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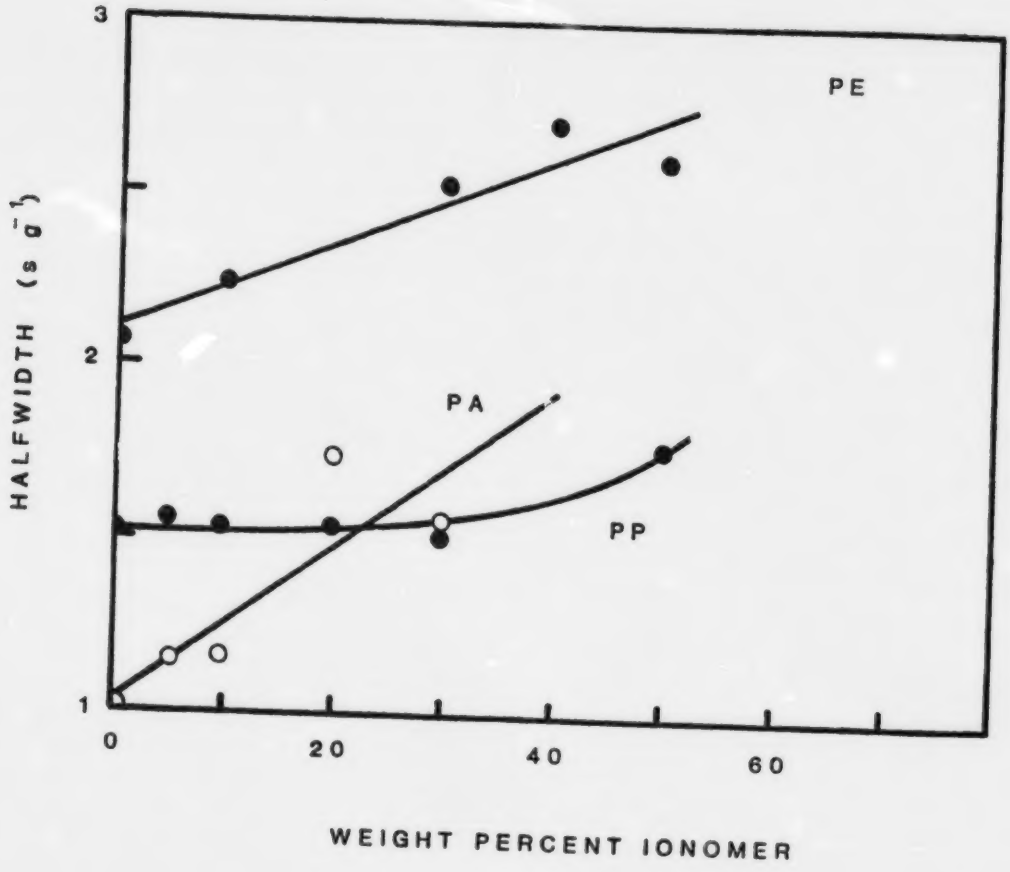

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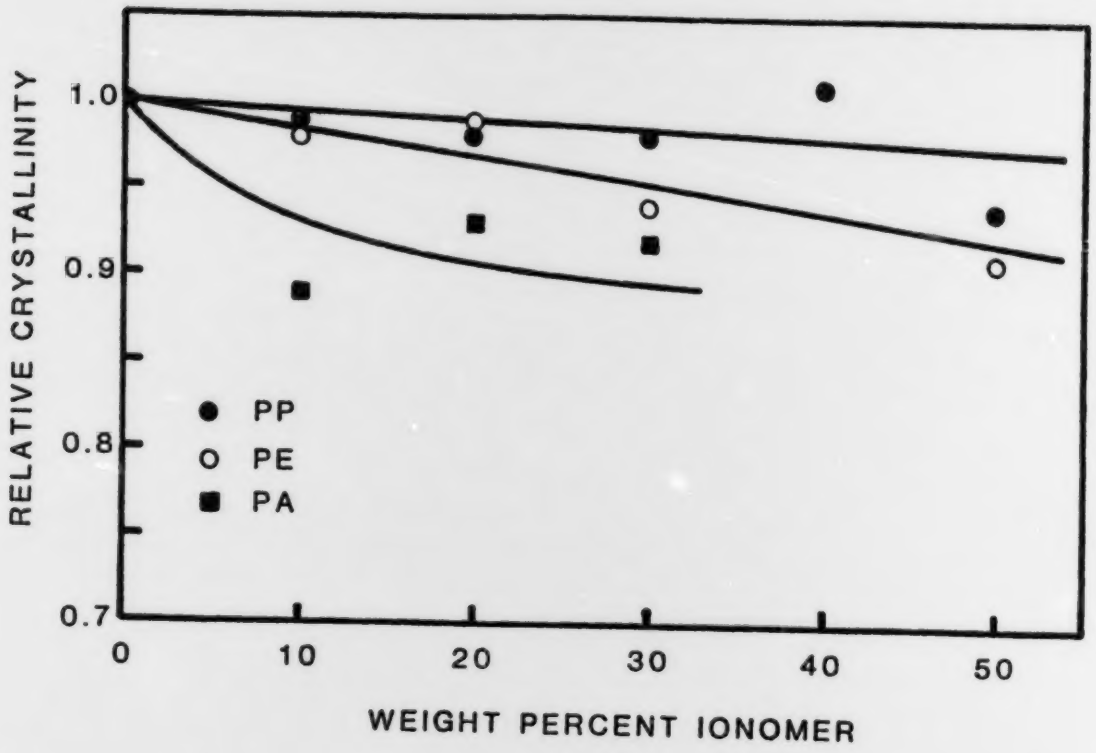

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